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Application of simplex lattice design for development of moisture absorber for oyster mushrooms

Sílvia Azevedo[a], Luís Miguel Cunha[a,b,*], Pramod V. Mahajan[c], Susana Caldas Fonseca[b, d]

[a] *DGAOT, Faculty of Sciences, University of Porto, Porto, Portugal*
[b] *REQUIMTE, University of Porto, Portugal*
[c] *Department of Process & Chemical Engineering, University College Cork, Cork, Ireland*
[d] *Escola Superior de Tecnologia e Gestão, Instituto Politécnico de Viana do Castelo, Viana do Castelo, Portugal*

Abstract

Polymeric films used in MAP have lower water vapour transmission rates relative to the transpiration rates of fresh produce such as oyster mushrooms (*Pleurotus ostreatus*). As a consequence, water condensation may be found inside the package, promoting decay of the product. The use of moisture absorbers to control the relative humidity inside packages is effective in reducing saturation and condensation for fresh produce. However, common moisture absorbers have low absorption capacity or, in opposite, fast rate of absorption which is undesirable for storing high transpiring products. Therefore, this study was undertaken in order to develop a moisture absorber with high moisture holding capacity. The experiment was designed according to a simplex lattice method with three factors (calcium oxide, sorbitol and calcium chloride) and a range of 0.2 – 0.6 g of desiccant mass. These three desiccants were mixed in varying proportions and the change in moisture content of each of the mixed desiccants was measured at regular intervals up to 5 days at 10 ºC. Pareto analysis showed that calcium chloride had the most significant effect on final moisture content of mixed absorber. The optimized desiccant mixture contained 0.5, 0.26 and 0.24 of calcium oxide, calcium chloride and sorbitol respectively yielding moisture holding capacity of 0.813. These results present good perspectives for the application of a moisture absorber for packaging of oyster mushrooms.

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Keywords: calcium chloride; calcium oxide; packaging; simplex lattice; sorbitol

1. Introduction

Packaging is a fundamental tool in order to retain general quality and the use of Modified Atmosphere Packaging (MAP) in postharvest preservation of horticultural commodities has been recognized as one

*Corresponding author. Tel.: +351-252 660 400; fax: +351-252 660 760.
E-mail address: *lmcunha@fc.up.pt*

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important technology to reduce losses, maintain quality and extend shelf life throughout the distribution chain [1, 2]. MAP has been extensively studied for mushrooms, with positive effects regarding quality. However, condensation of moisture inside the packages, off odour and off colour developments are common problems in mushrooms packing, due to the low water vapour transmissions rates (WVTR) of the films used [3-7]. The excess of water that moisten produce surface will cause an unpleasant package appearance but also increase water activity and consequently create the ideal conditions for microbial growth and subsequent decay of the product [5, 6].

A possible solution to control the in-package relative humidity (IPRH) and therefore extend the shelf life of respiring produce is the use of moisture absorbers [8-11]. The use of sorbitol, xylitol, sodium chloride and potassium chloride has already been applied in green tomatoes, increasing their shelf-lives and suppressing mold growth [8].

Ben-Yehoshua et al. [10] used calcium chloride (CaCl2) to control IPRH of bell peppers and the use of 5 g of desiccant per fruit maintained the RH between 80 and 88%, with less lost weight and higher quality maintenance. In the work of DeEll et al. [11] the addition of sorbitol in MAP allowed a better maintenance of general quality of broccoli heads when compared with control treatment.

Regarding mushrooms, very few studies were conducted on the use of desiccants in fresh produce packaging. Roy et al. [5, 6] studied the use of sorbitol (15 g sorbitol/100 g mushrooms) to control IPRH of Agaricus mushrooms at 10℃, concluding that the desiccant application in the package increased the product shelf life and that higher sorbitol quantities increased product weight loss. Other commercially available food-grade moisture absorbers such as clay and silica were used in modified humidity packaging of fresh mushroom [7]. The authors obtained global better storage quality regarding maturity index and discoloration when 9 minipacks (3.5 g each pack) were used in a 225 g tray.

For Pleurotus mushrooms, [12] also used sorbitol and silica gel (10–15 g/150 g of mushrooms) to control IPRH, concluding on one hand, that sorbitol deteriorated texture, whereas silica gel increased the weight loss of produce. In a different approach, [13] developed a moisture absorber for fresh mushrooms using different combinations of desiccants. The authors suggested a combination of bentonite, sorbitol and CaCl2 (in proportions of 0.55, 0.25 and 0.2 g. g−1) to fit mushrooms requirements (moisture holding capacity of 0.9 g. g−1 mixed desiccant that remained in powder form during 120 h of storage at 10 ℃). Moreover, appearance of Agaricus mushrooms improved with the use of 5 g of mixed desiccant in 250 g of mushroom punnets when compared with produce packed without desiccant.

Oyster mushroom (Pleurotus ostreatus) is a common edible mushroom, highly appreciated for its unique flavour and nutritional composition. Once harvested, Pleurotus deteriorate rapidly and high weight losses are found in postharvest period [6, 12, 14]. In particular with Pleurotus, very few studies can be found regarding the use of moisture absorbers to achieve higher quality retention [6, 12].

Existing moisture absorbers approved for use in food packaging have low absorption capacity or absorb moisture too quickly, making them unsuitable for food packaging. This study aims to develop a moisture absorber with the correct moisture holding capacity for mushrooms. This will be achieved by combining three desiccants, calcium oxide (CaO), sorbitol and CaCl2 in varying proportions and identifying the combination of the three desiccants which gives optimum performance. Simplex lattice technique was used to design the experiments and optimize the proportion of ingredients for the mixed desiccant.

2. Materials & Methods

Three desiccants selected for the present study were CaO, $CaCl_2$ and sorbitol. Each desiccant was oven dried at 60 ºC for at least 1 h before mixing. Simplex lattice design was used to determine the number of experimental runs and the proportion of three desiccants in each experimental run (Table 1). It is a mixture design in which sum of the fractions of the desiccants is unity [15].

Table 1. Proportion of components used in each mixture of desiccant.

Mixture #	Component proportion		
	CaO	$CaCl_2$	Sorbitol
1	0.60	0.20	0.20
2	0.20	0.60	0.20
3	0.20	0.20	0.60
4	0.33	0.47	0.20
5	0.33	0.20	0.47
6	0.20	0.33	0.47
7	0.47	0.33	0.20
8	0.47	0.20	0.33
9	0.20	0.47	0.33
10	0.33	0.33	0.33
11	0.47	0.27	0.27
12	0.27	0.47	0.27
13	0.27	0.27	0.47
14	0.33	0.33	0.33

Moisture absorption of each mixture was measured at 10 ºC and 96% RH. Individual small plastic trays were used to hold 1 g of each of the 14 mixtures in an air tight plastic container (6.5 L). In order to create 96% RH, a saturated salt solution of potassium nitrate was placed at the bottom of the plastic container. Plastic containers holding the different mixtures at 96% RH were sealed tightly with plastic cap and vaseline and then transferred to an incubator (Sanyo MIR 253), providing the 10 ºC (±0. 2 ºC). The plastic trays were weighed at regular intervals and the moisture content (M_t) of desiccant was expressed in terms of g water g^{-1} desiccant as:

$$M_t = \frac{W_f - W_i}{W_i} \qquad (1)$$

where M_t is the moisture content of desiccant at time *t* (g water g^{-1} desiccant), *t* is time (h), W_{i} and W_t are the weight of desiccant (g) in the beginning and at time *t*. For each set of the desiccant, 3 replicates were performed and the entire set of experiments was replicated twice, with a total of 6 replicate for each mixture. Results were analyzed by non-linear regression with moisture content as the dependent variable, using *Statistica* software (Version 7, Statsoft, USA).

3. Results and Discussion

The experimental data showed that the weight of the mixed desiccant increased over time (Figure 1). Moisture was absorbed rapidly at first and then the slope began to level off indicating that moisture was gradually absorbed more slowly as the mixture reached equilibrium. Shelf life of Pleurotus mushrooms is about 2 to 3 days at 10 ºC [16], therefore moisture content of mixed desiccant up to maximum 5 days was considered as equilibrium moisture content. Moisture uptake for mixture #2 was more rapid than for mixture #13 (Figure 1). The rapid moisture uptake and higher moisture holding capacity (MHC) of mixture #2 could be because it contained higher proportion of $CaCl_2$ than other two desiccants.

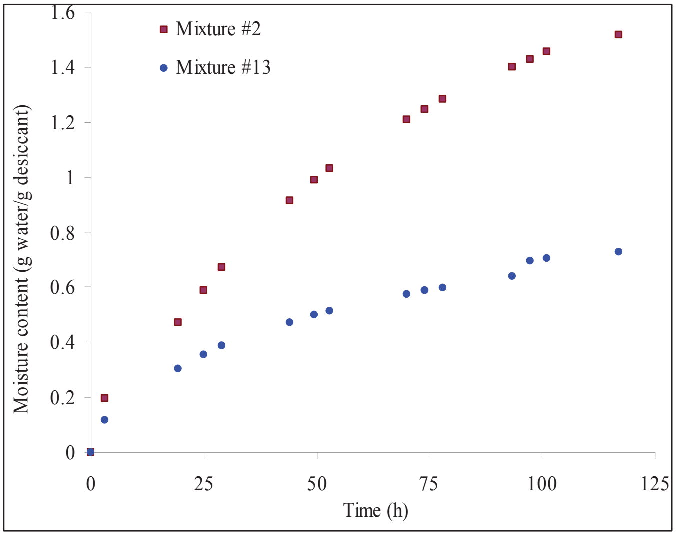

Fig. 1. Typical moisture absorption kinetics for mixture #2 & #13 at 10°C and 96% relative humidity

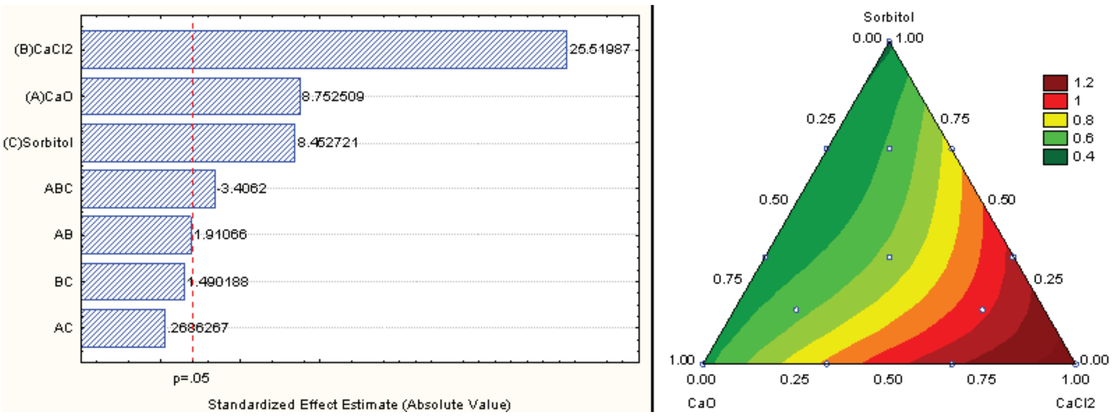

Fig. 2. Standardized Pareto chart (a) and contour plot (b) for accounting the effect of each of the individual components and the mixing component in the total moisture holding capacity. The dashed vertical line corresponds to the 95% confidence limits

Figure 2 shows the Pareto chart and contour plot accounting for the effect of mixing desiccants on MHC. The Pareto chart indicated that all 3 components have a significant impact on moisture holding capacity of the mixed desiccant. $CaCl_2$ had the most significant impact on moisture holding capacity of the mixed desiccant followed by CaO and Sorbitol. These results are in agreement with previous studies [13, 17] since $CaCl_2$ is known for its strong hydrophilic properties. Moreover, it can be seen that the ternary mixture has also a significant effect on moisture holding capacity.

Since the 3 components have effect in the MHC, a cubic model (Eq 2) was fitted to the experimental data, where A is CaO, B is $CaCl_2$ and C is sorbitol. The coefficients (α's) of the cubic model and other statistical information are shown in Table 2 and 3. The coefficient of determination (R^2) was above 0.9 which indicated a good fit for both responses.

Table 2. Analysis of variance of the model

	SS	df	MS	F	p
Model	5.600	6	0.933	66.29	< 0.001
Total Error	1.014	72	0.014		
Lack of Fit	0.232	6	0.039	3.27	0.007
Pure Error	0.781	66	0.012		
Total Adjusted	6.614	78	0.085		

Table 3. Coefficients and respective standard errors of the cubic model

Coefficient	Value	SE
α_1	0.466	0.053
α_2	1.244	0.049
α_3	0.381	0.045
α_{12}	0.443	0.232
α_{13}	0.061	0.227
α_{23}	0.335	0.225
α_{123}	-4.349	1.277

$$MHC = \alpha_1\ A + \alpha_2\ B + \alpha_3\ C + \alpha_{12}\ A\,B + \alpha_{13}\ A\,C + \alpha_{23}\ B\,C + \alpha_{123}\ A\,B\,C \tag{2}$$

where A, B and C indicate CaO, $CaCl_2$ and Sorbitol proportions in the mixture, respectively. $CaCl_2$ has the stronger influence on MHC, in contrast with sorbitol which showed least effect on MHC. ABC is negative, meaning an antagonist blending effect, which will decrease the MHC of the mixture through the storage time.

From Figure 2 it can be seen that if high MHC is desired, higher levels of $CaCl_2$ should be used. However, in order to develop a moisture absorber for respiring produces, the selected moisture absorber must stay in the powder form throughout the storage life of the produce. Therefore, addition of a specific amount of CaO and sorbitol should be mixed. In order to optimize the desiccant mixture, the proportion of $CaCl_2$ was fixed at 0.26 mass fraction and the maximum MHC at any combinations of CaO and sorbitol was obtained using the solver Tool in Microsoft Excel. The results show that in order to obtain a maximum MHC of 0.813 g water per g of desiccant, a mixture of CaO, $CaCl_2$ and sorbitol should be prepared with respective mass fractions of 0.50; 0.26 and 0.24, respectively.

4. Conclusion

The $CaCl_2$ had the most significant effect on final moisture content of mixed absorber. The optimized desiccant mixture contained 0.50, 0.26 and 0.24 mass fractions of CaO, calcium chloride and sorbitol, respectively. This new mixed desiccant has the ability to yield a moisture holding capacity of 0.813 g water g^{-1} desiccant and remains in powder form for at least 5 days at 10ºC. These results present good perspectives for application of mixed desiccant for packaging of oyster mushrooms packaging.

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